Light-Soaking and Open-Circuit Voltages in Solar Cells: Insights into a-Si:H Metastability

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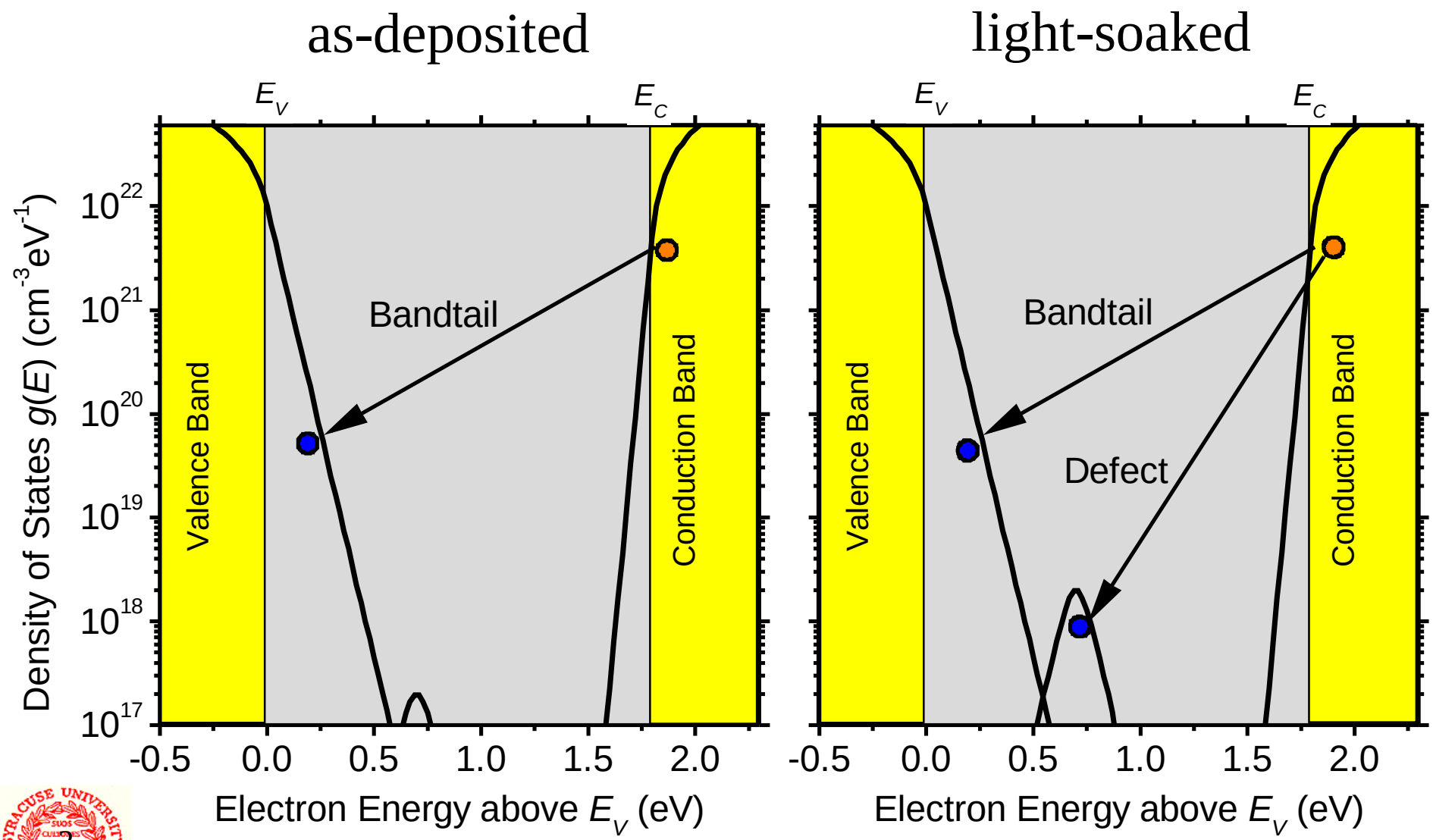
Recombination & the Open-Circuit Voltage of a-Si:H Solar Cells

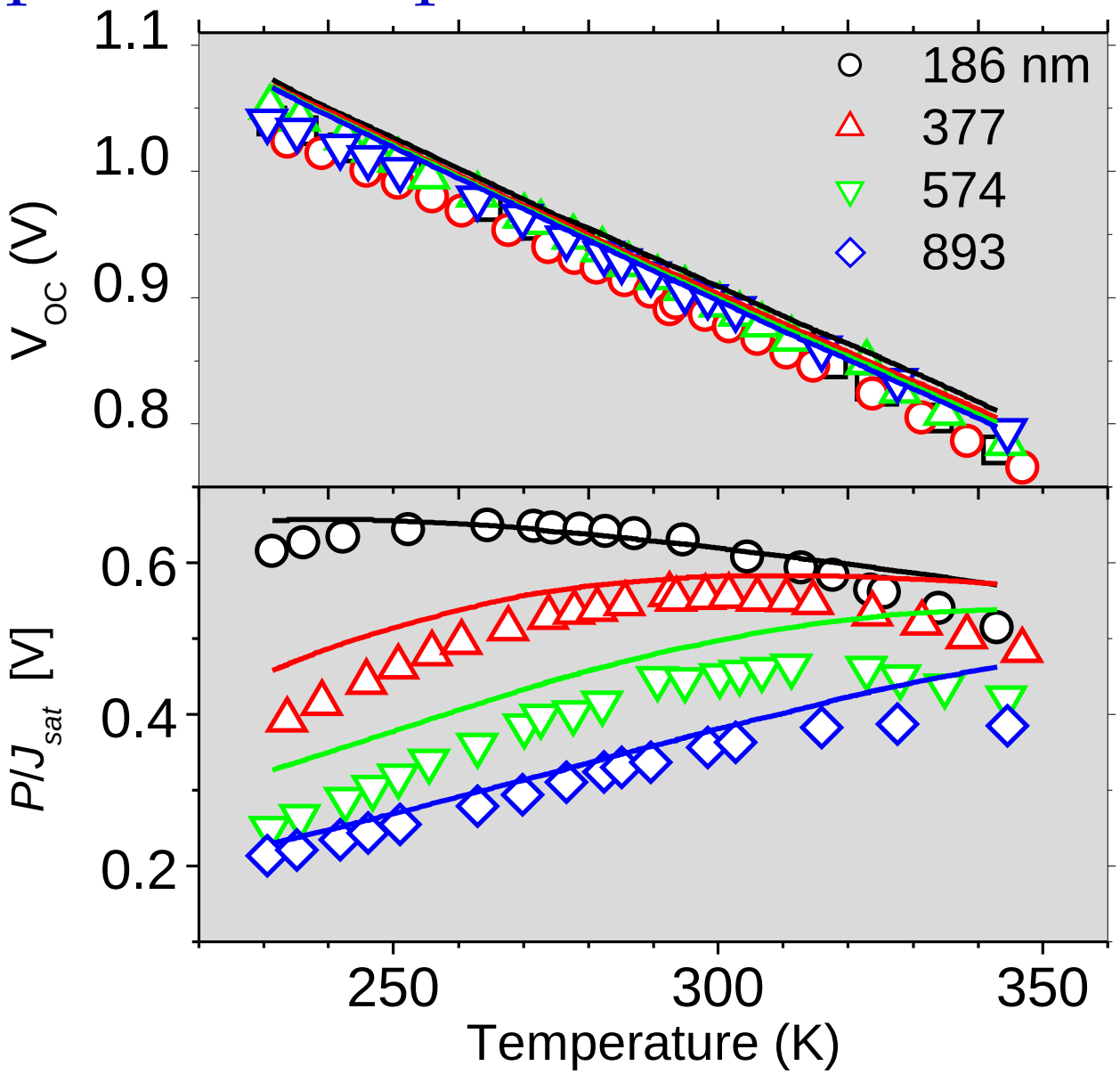
- a-Si:H cells are **low-mobility** cells
  - By definition: slow carrier (hole) drift is the primary limitation to power generation in low-mobility cells
  - *Ipso facto:* electron-hole recombination is **not** the primary limitation to a-Si:H cell efficiency.
- **However** … electron-hole recombination is probably the primary source of metastability
  - Understanding recombination is thus – indirectly – of great importance to the cells.
- We address recombination & metastability by studying V_{OC}

Photocarrier Recombination in a-Si:H Solar Cells



As-deposited Solar Cells (United Solar): Temperature-Dependence

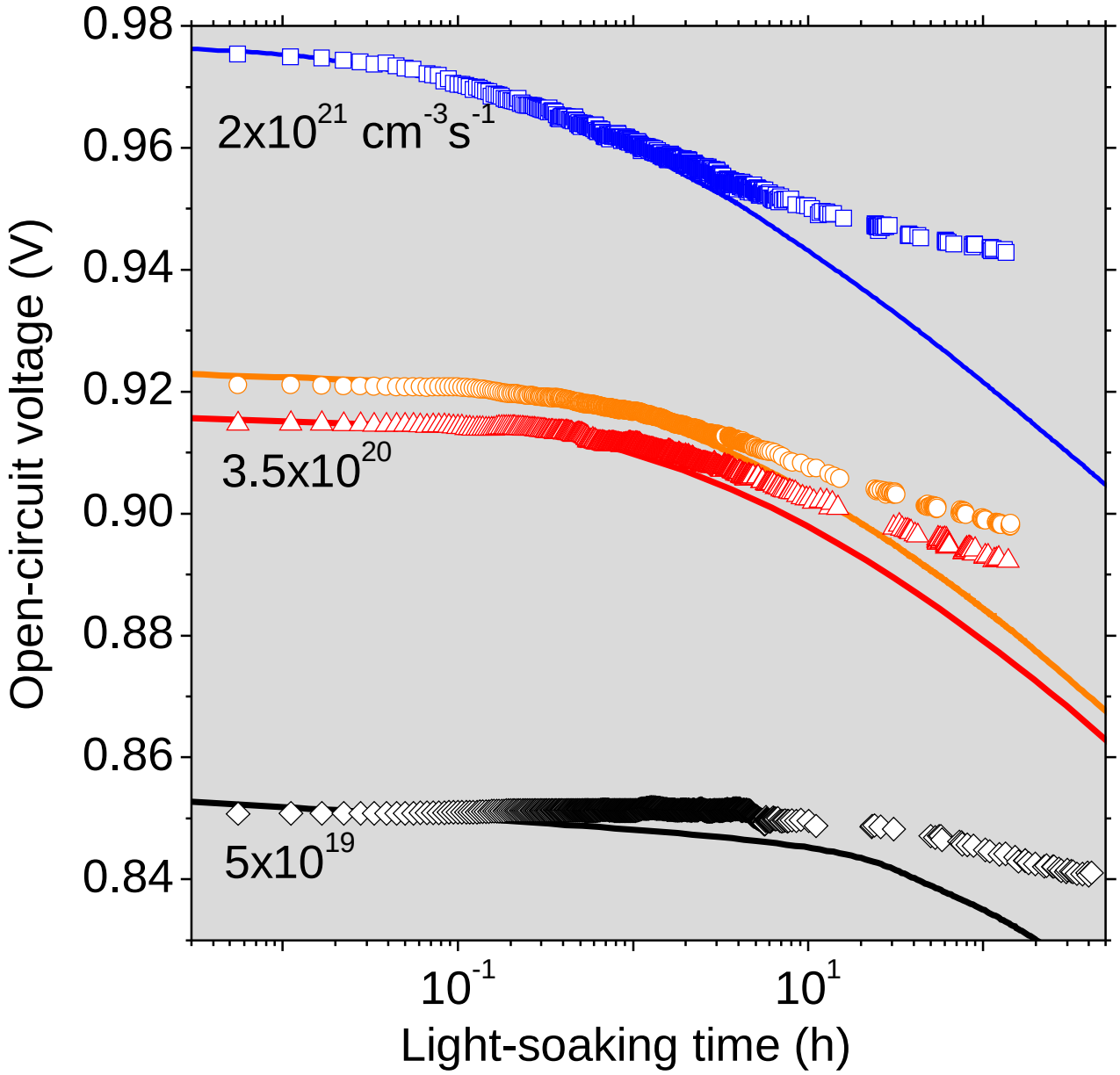
Curves: Bandtail model



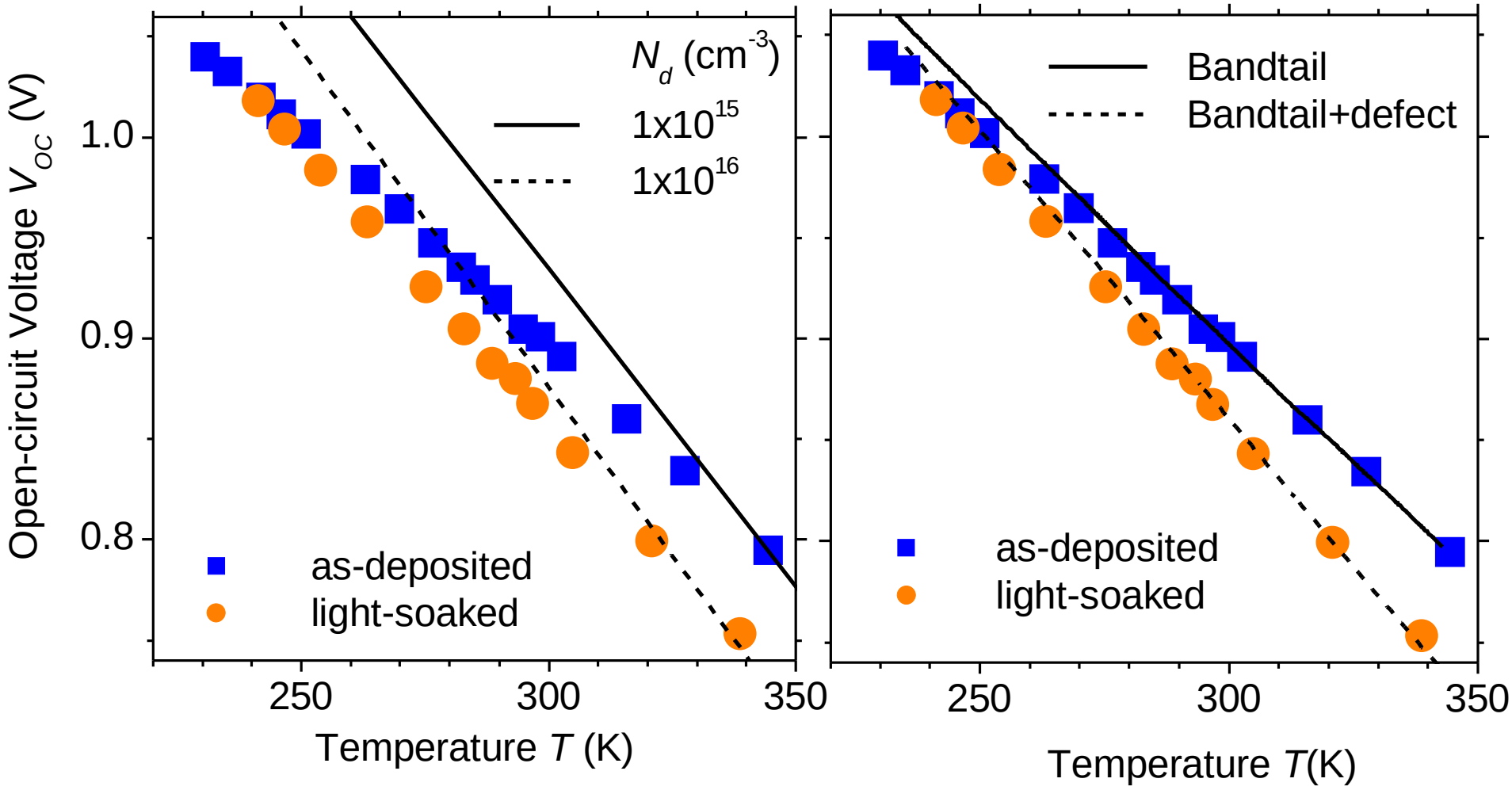
Summary of our Conclusions About United Solar a-Si:H Solar Cells

- Photocarrier recombination fits the usual bandtail+defect picture @ solar intensities - but
  - As-deposited: primarily bandtail
  - Light-soaked: bandtail *perturbed* by defects
- Recombination processes probably drive light-soaking. Kinetics ("$t^{1/3}$") mostly agrees with:
  - Hydrogen-collision
  - Driven by bandtail recombination
- Tail/Defect Crossover between bandtail & defect recombination appears to be on the same timescale as "light-induced annealing."

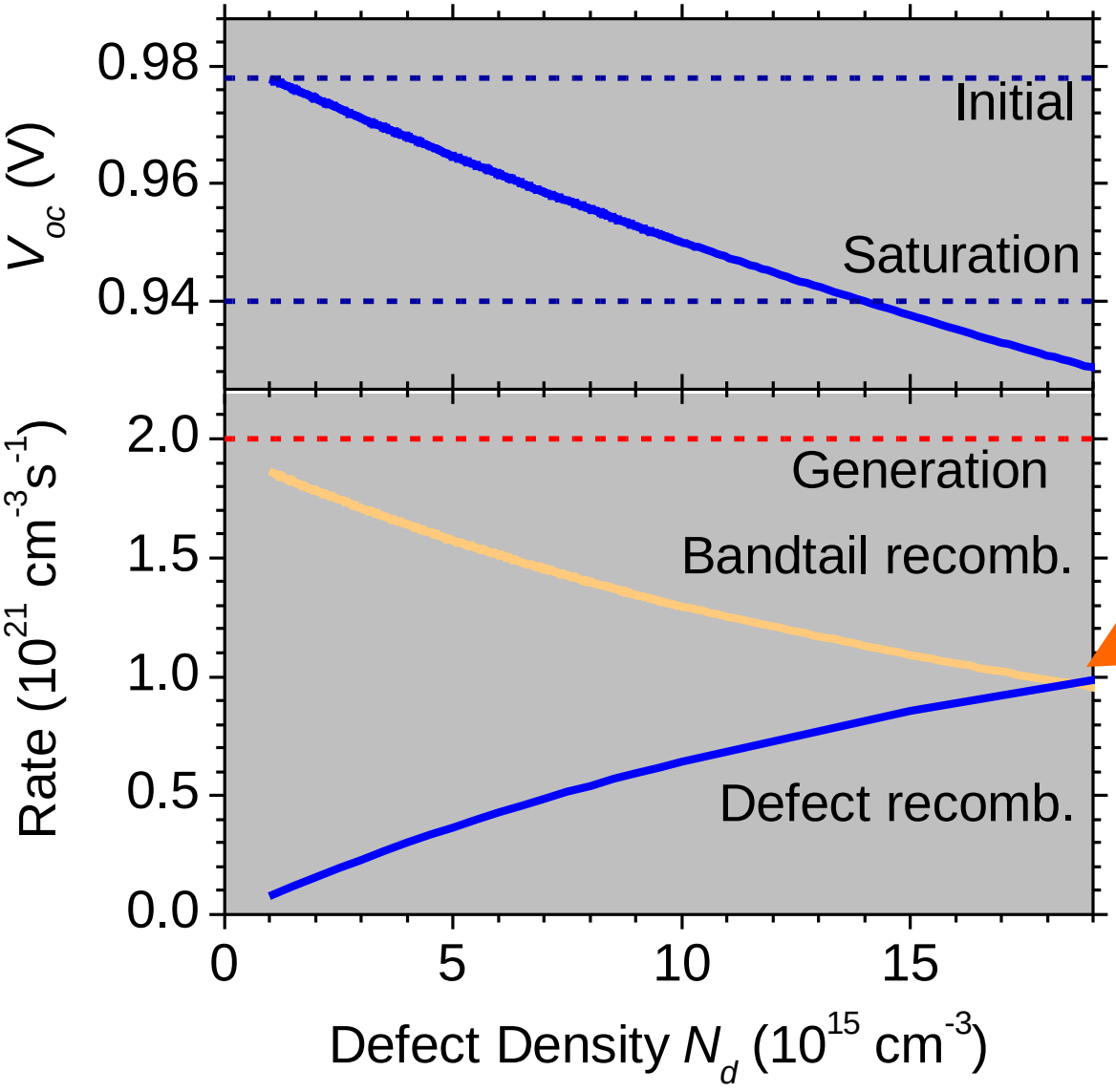
Light-soaking Kinetics of V_{OC}



Light-soaking & Temperature Dependence of V_{OC}: Low-temperature Convergence



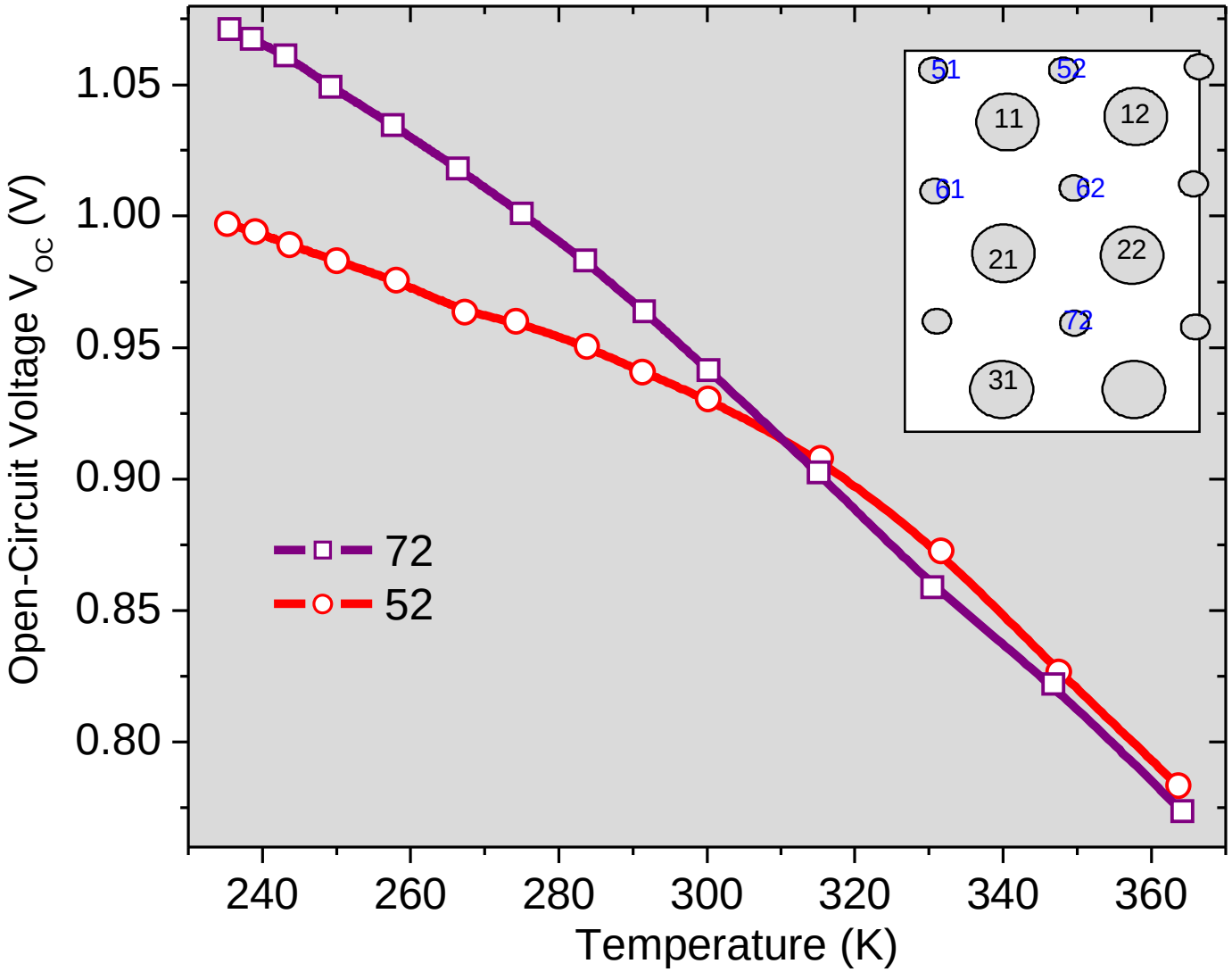
Recombination & Light-Soaking: Predictions of the Bandtail+Defect Model



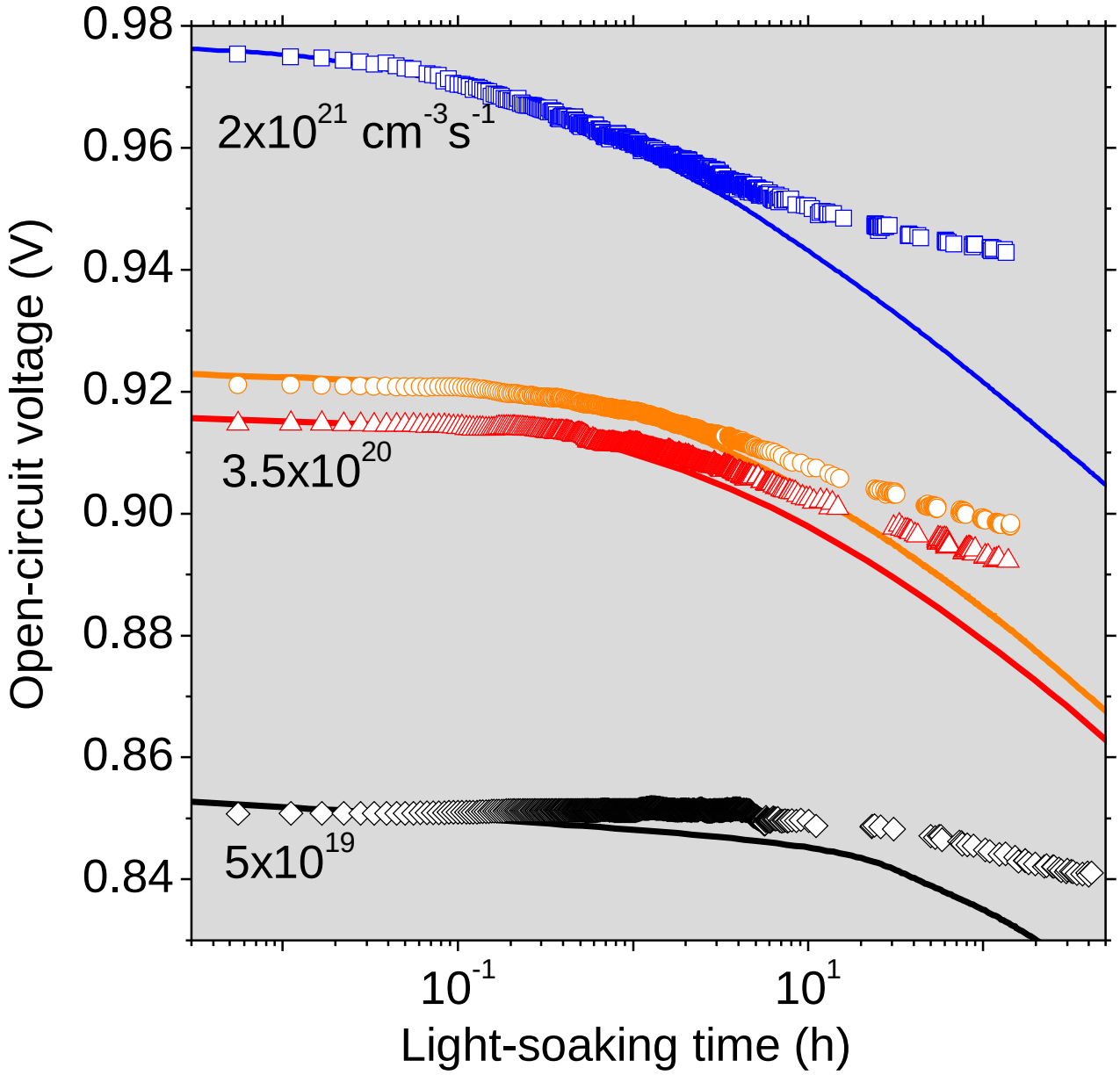
Tail/Defect Crossover

(never actually observed)

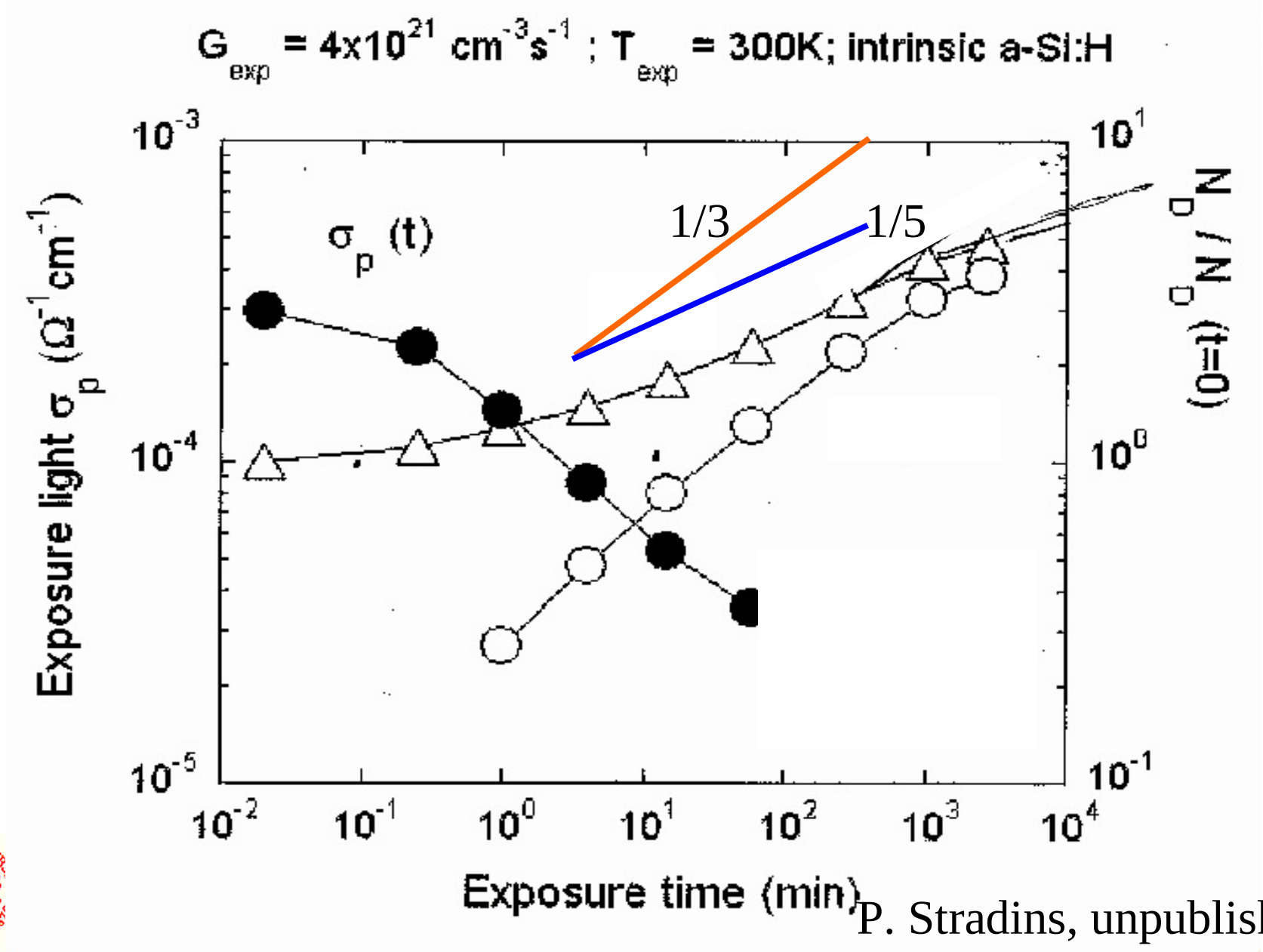
$V_{OC}(T)$ – edge & middle cells



Light-soaking Kinetics of V_{OC}



The Notorious $N_D \approx t^{1/3}$ "Law"



P. Stradins, unpublished

SJT Model for "$t^{1/3}$" Kinetics

- SJT Derivation of $t^{1/3}$

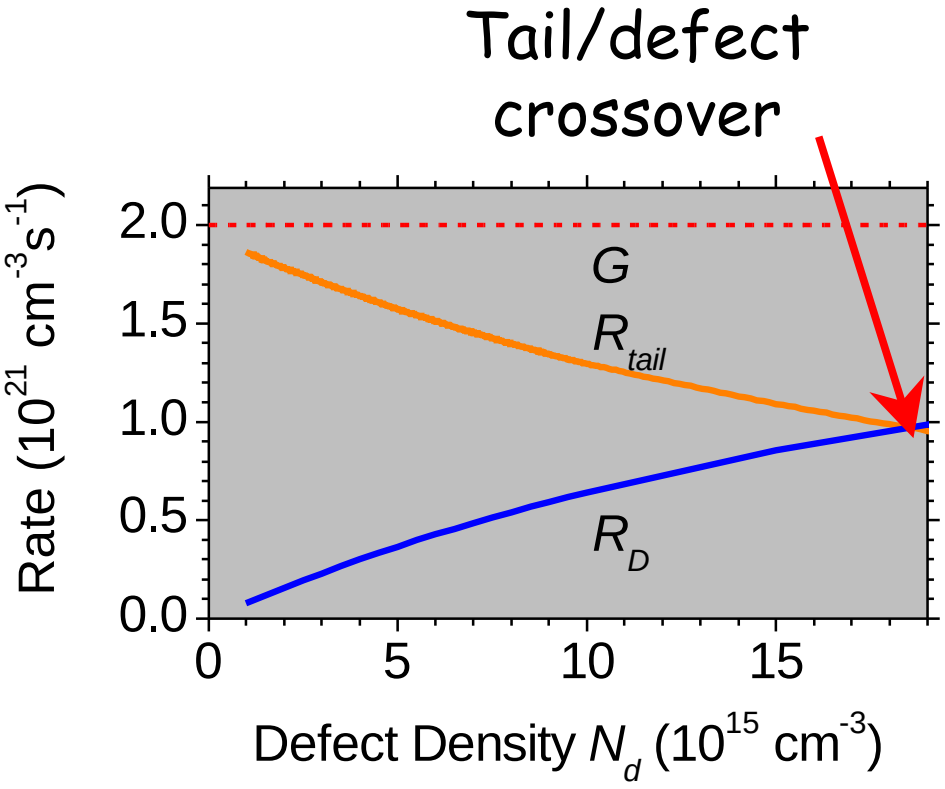
$$\frac{dN_d}{dt} \propto R_{tail}$$

$$R_D \propto G$$

$$R_{tail} \propto N_D^{-2}$$

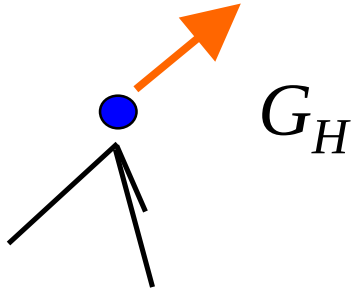
$$N_D^3(t) = N_{D,0}^3 + C_{SW}^3 G^2 t$$

- Problems with SJT model
  - Low-temp. degradation
  - Degradation by pulsed light in films
  - (present) V_{OC} studies in films

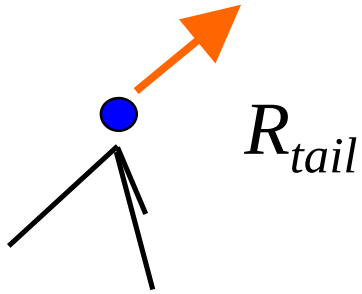


Hydrogen-Collision Models for "$t^{1/3}$" Kinetics

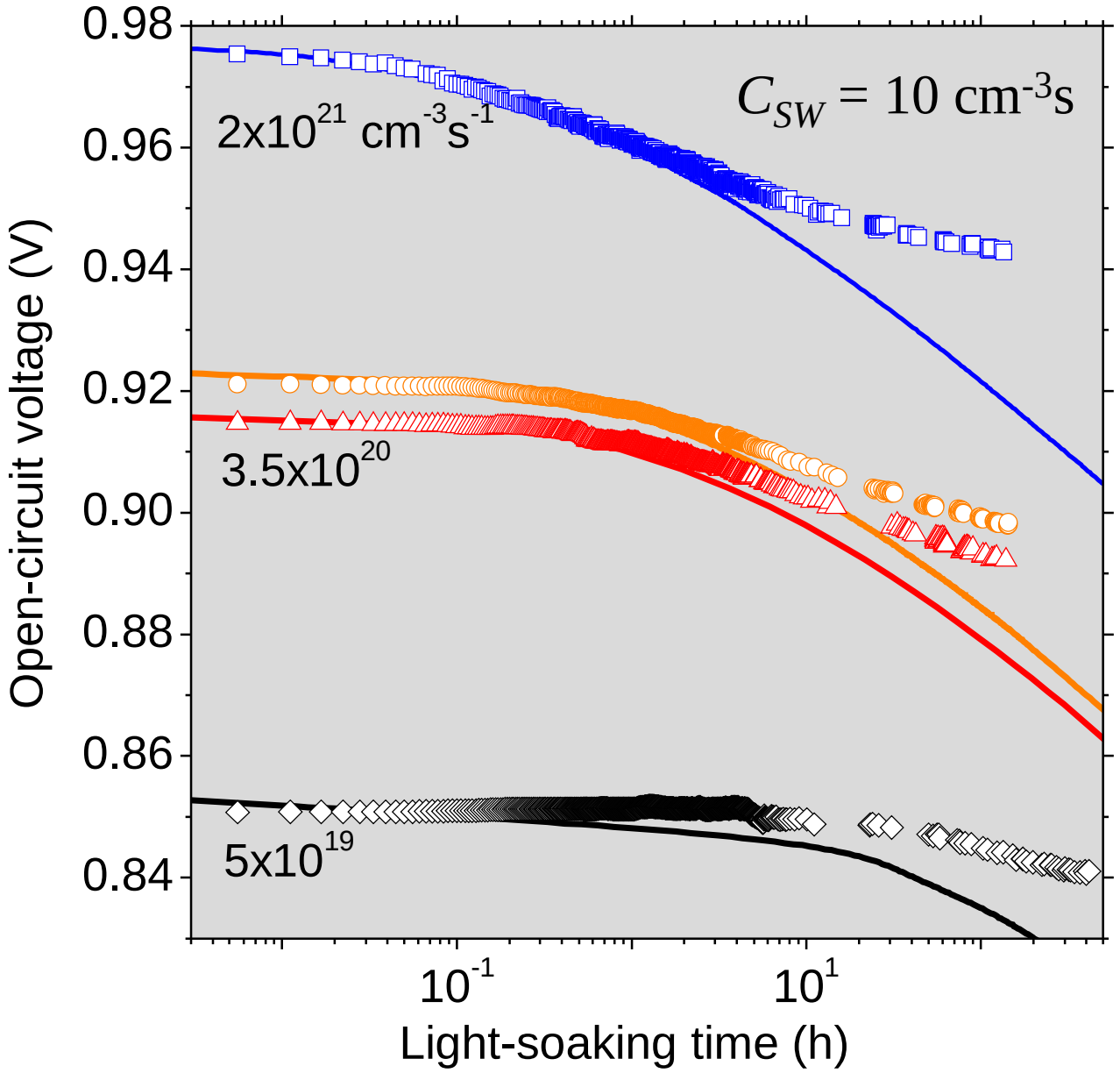
H-collision $\quad \dfrac{dN_d}{dt} \propto H_m^2 = C_{SW}\left(\dfrac{G_H}{N_d}\right)^2$



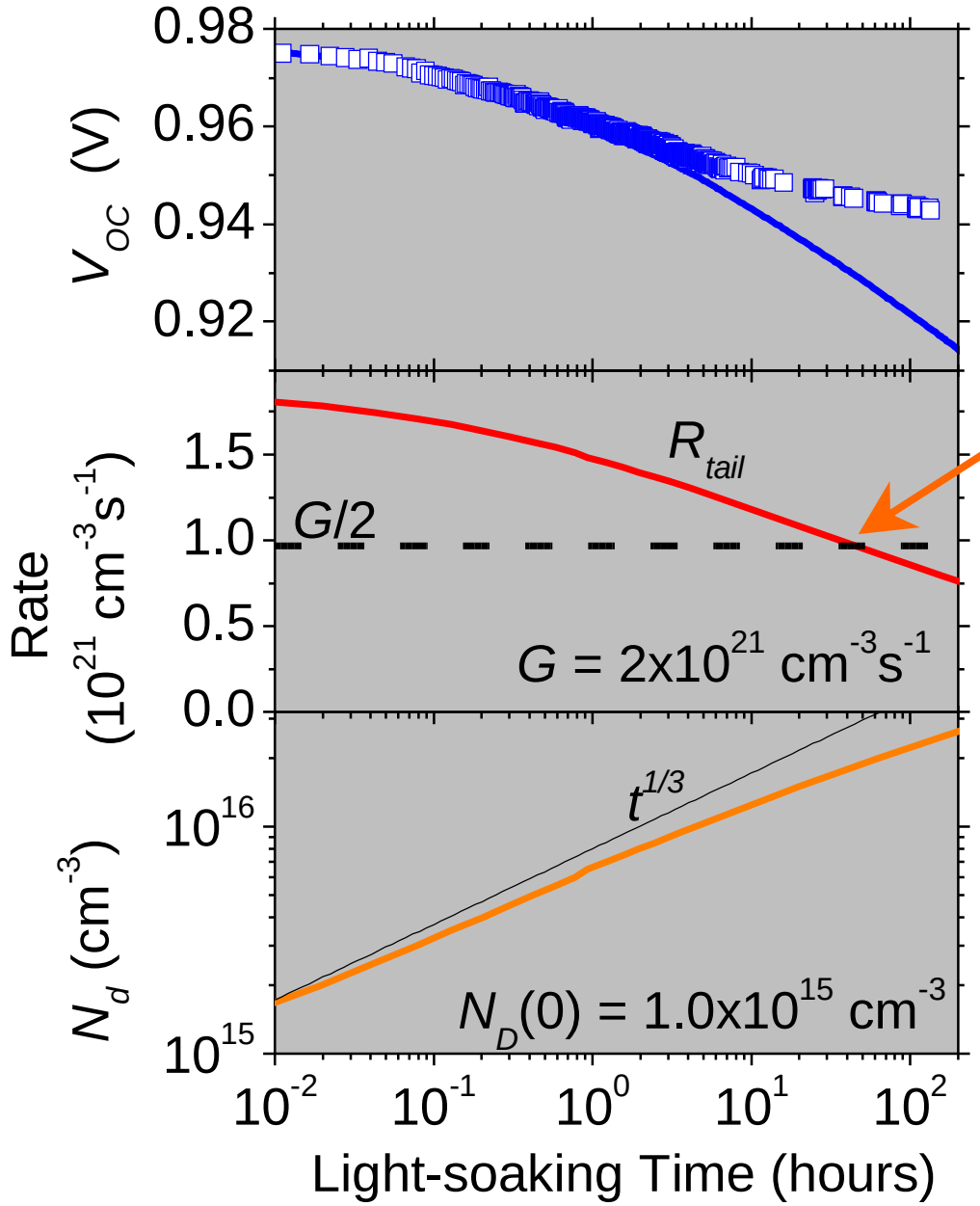
H-collision (modified) $\quad \dfrac{dN_d}{dt} \propto H_m^2 = C_{SW}\left(\dfrac{R_{tail}}{N_d}\right)^2$



H-collision Predictions for $V_{OC}(t)$

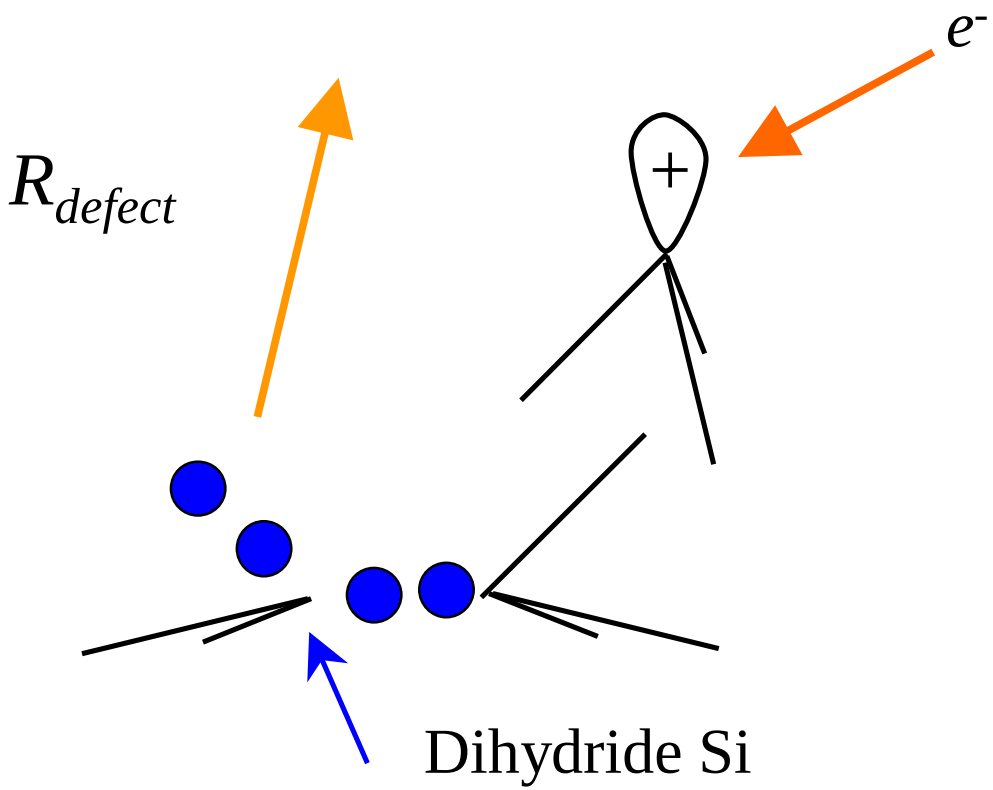


V_{OC} Decline & Recombination Crossover



Tail/defect Crossover

Why are recombination crossover & light-induced annealing at the same timescale?



Future Device Physics Pathways

- a-Si tail/defect crossover & self-limitation of metastability
  - Suggests universal aspect of metastability that transcends detailed defect reactions and detailed photocarrier processes
- a-SiGe cells more critical (triple j. technology).
  - Probable that cells are low-mobility type, but little is known about the hole mobilities.
  - Self-limitation of metastability? Much less known about kinetics than for a-Si.
- Speculation
  - Better cells will come from better hole drift.

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$t^{1/3}$ & $t^{1/5}$ laws

$$\frac{dN_D}{dt} = C_{SW}\,\frac{R_{tail}^2}{N_D^2}$$ Modified H-collision equation

Early times	$R_{tail} = G$:	$N_D \propto t^{1/3}$	$\Delta V_{OC} < (k_B T/e)$
Long times	$R_{tail} \propto 1/N_D$:	$N_D \propto t^{1/5}$	$\Delta V_{OC} = -(k_B T/e)\ln\left(t^{1/5}\right)$